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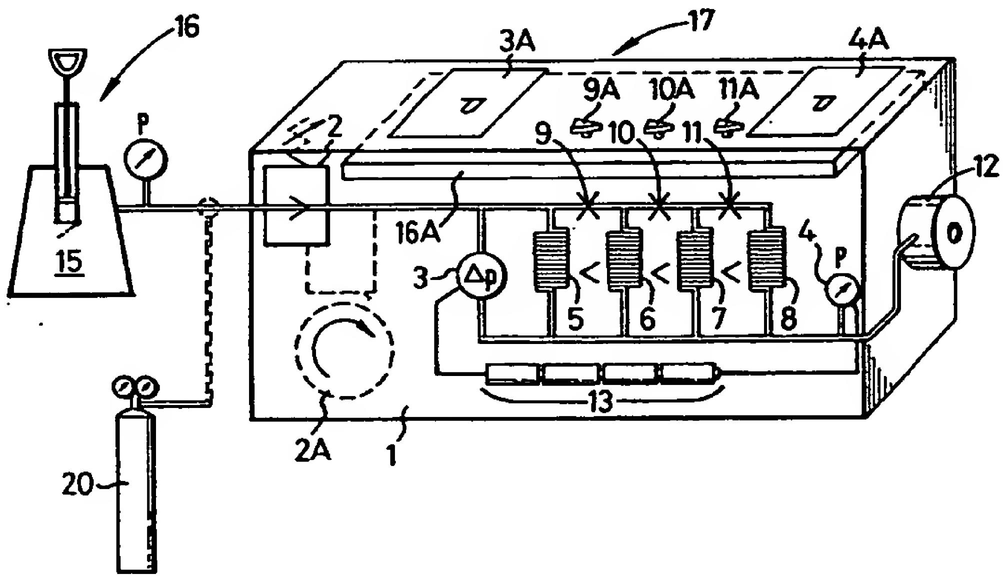
(54) Title: PROBE PERMEAMETER



(57) Abstract

The present invention provides a probe permeameter (1) comprising a source of compressed gas (15, 20), a pressure regulator (2), at least one open coil of fine tubing (5) and at least one valve controlled coil of fine tubing (6, 7, 8) disposed in series, pressure indicating means (3A, 4A) respectively upstream and downstream of said coils, and a gas nozzle (19) operatively associated with a sealing annulus (21), whereby with the nozzle urged into contact with a test specimen, gas is delivered at laminar flow and wherein the pressure indicating means indicates the differential pressure generated in the specimen and hence the permeability thereof. The permeameter is adopted for use with a manually pressurisable gas source (15) which allows the device to be readily transported.

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PROBE PERMEAMETER

The present invention relates to a probe permeameter for testing the permeability of porous samples such as, for example, samples of rock. Portable probe permeameters have been known for some years but are bulky to carry and difficult to use in hostile environments. This is in part because the probe assemblies themselves are ungainly, but also more importantly, because they rely on access to air compressors or canisters of compressed gas which if small enough to carry are usually too small for prolonged investigations.

The present invention seeks to provide therefore a probe permeameter of small size which can be used with a manually pressurisable container for compressed gas if desired, and which can be successfully utilised in hostile environments without the necessity of transporting numbers of compressed gas cylinders.

Further the device of the invention is sufficiently light so that it can be used easily from substantially any position, even above the head.

According therefore to a first aspect of the invention there is provided a probe permeameter comprising a source of compressed gas, a pressure regulator, at least one open coil of fine tubing and at least one valve controlled coil of fine tubing disposed in parallel, pressure indicating means respectively upstream and downstream of said coils, and a gas nozzle operatively associated with a sealing annulus; whereby with the nozzle urged into contact with a test specimen and sealed thereto by means of the sealing annulus, gas is delivered at laminar flow to the sample, and wherein the pressure indicating means indicates a differential pressure indicative of the permeability of said test specimen. The source of compressed gas is preferably a manually pressurisable container of known type which can be pressurised

by means of an air pump to a pre-determined value. The compressed gas source may however in the alternative be a gas canister of, for example nitrogen gas where this is available and convenient to use.

Preferably there is provided a plurality of valve controlled fine tube coils, connected in series, so as together to selectively induce laminar flow at progressively higher gas through-puts. The pressure indicating means upstream may be a differential pressure gauge and the pressure indicating means downstream may be a pressure transducer and a pressure indicating means. Preferably the pressure gauges are electrically driven by a battery and by preferably re-chargeable battery. An output for computerised data may also be included.

The nozzle may be provided at its operative end with a sealing annulus formed for example of a resilient plastics or rubber to seal against the sample under test. Preferably the nozzle is remote from the device and connected thereto by a gas impermeable extension conduit. A switch either on the body of the permeameter or adjacent a probe tip on the body of the permeameter can be utilised to actuate the gas flow, and to switch on data gathering means. Alternatively the sealing annulus maybe operatively connected to said valve to open the same when pressed into contact with the specimen and the data gathering means may be switched on either manually or actuated by gas flow when steady state gas flow through the sample has been achieved.

By means of these arrangements in accordance to the present invention a series of permeability measurements may be made on a series of specimens even in the most hostile environments without the necessity for the transport of gas cylinders and with the advantage of light weight whereby the whole device can be readily carried as hand-baggage or back-packed.

The invention will now be described, by way of illustration only, with reference to Figures 1 and 2 of the accompanying drawings which shows in diagrammatic plan a flow diagram indicative of a device as just described, and wherein

Figure 1 shows a side elevation part section of a probe permeameter according to the invention, and

Figure 2 shows a probe assembly in diagrammatic transverse section.

The permeameter in accordance to the present invention maybe conveniently described with reference to a gas source (16) and with regard to a probe assembly (17).

Turning first to gas source (16) there is provided a manually pressurisable container (15) with a manually actuated pump and pressure valve. This operates up to about 5 bar. As an alternative a nitrogen cylinder (20) may be connected via a bottled gas regulator to the same compressed gas input, but the device is predicated usually on the utilisation of the manually pressurisable container (15). The gas source may, for example, be a Hozelock Killaspray 8 garden spray adapted by sleeving the pump cylinder and fitting a 0-6 bar pressure gauge.

The probe assembly (17) is comprised of a body (1) having a generally rectilinear configuration and having in this instance an overall length of about 30 cm. Downstream of the gas sources (15) and (20) and within the body (1) is an upstream pressure regulator (2) for the system. Said pressure regulator is adapted to control the gross flow of gas into the assembly (17). The pressure regulator (2) is suitable for dead end flow applications and is used to set up maximum gas injection pressure within the flow system when the probe tip (12) or the sealing annulus (21) is sealed against a totally impermeable substrate prior to measurement. A Fairchild high

flow capacity precision non-relieving regulator valve is suitable for use in this particular instance. The pressure regulator (2) can be set by a regulator wheel (2A) to allow a high or low volume of gas to pass therethrough depending upon the intended substrate for testing. Where for example the substrate is highly porous, such as when utilising the assembly on a chalk face for example, a high flow rate will be required, whereas on harder materials such as granite a lower flow rate will be required.

Downstream of the pressure regulator (2) is a first through-flow fine bore steel capillary coil (5) about 0.265m in total length but coiled into a space of about 2.5cm; in this instance with a capillary diameter of 0.508mm. The first coil (5) is through-flow in the sense that gas will always flow through the coil (5) to the nozzle (19) via gas conduit (18) and has a length necessary to ensure laminar flow at 2cc/minute. Upstream of the coil (5) and connected to both the upstream and downstream sides of the coil (5) is a differential pressure gauge (3). The pressure gauge (3) is in the form of a micromanometer to measure the pressure differential (ΔP) across selected laminar flow pathways. A suitable micromanometer is a Furness Controls Ltd: FC010, pocket manometer model (1).

Serially downstream of the coil (5) are coils (6,7 and 8) each formed of a fine bore high quality steel capillary tubing in a manner similar to coil (5). These have however respectively a laminar through flows at 20$^{\circ C}$ of 20cc/minute; 200cc/minute and 2000cc/minute. The capillary diameters are respectively 0.762mm (6);
2.159mm (7) and 2.997mm (8). Each of the coils (6), (7) and (8) are valved respectively at 9, 10 and 11 to allow the said coils (6),(7) and (8) to be actuated in series with coil (5) to allow a greater flow of air to pass under laminar flow into tube (18).
The (ΔP) pressure drop across the selected laminar flow

pathways is measured by the micromanometer (3) described above and used to calculate a normalised gas throughput which can be calibrated for permeability.

The valves (9), (10) and (11) act respectively to isolate or open laminar flow pathways. Although shown in component parts the coils and the valves (items 5 to 11) are preferably formed in a single light weight metal block to which other operative components may be conveniently attached.

Downstream of the coils (5 to 8) is a pressure transducer and a pressure indicator (4) actuated by a battery; preferably a re-chargeable battery (13). The pressure transducer and indicator (4) measures pressure within the flow system downstream of the laminar flow pathway during measurement to record gas injection pressure into an analytical substrate. A Druck DPI digital pressure indicator having a pressure range of 14.5 psi (RGA 1400) is suitable.

At the remote operative end of the conduit (18) lies the nozzle (19) which is provided with a sealing annulus (21), said sealing annulus being formed of a resilient rubber or plastics material and being adapted to seal against a rock or other specimen face when pressed there against by the nozzle (19). The annulus (21) is also provided with a screw top to allow zero flow setting with regulator (2A) as described above.

The conduit (18) is engageable within the probe tip (12) secured to the outer face of the body (1) and maybe of any convenient length to enable the operator to test samples remote from body (1).

The upper face of the body (1) is provided with two displays to show at (3A) the output from the micromanometer (3), and at (4A) the output from the pressure transducer (4). Also extending from the upper face of the body (1) are valve

operating elements (9A), (10A) and (11A) respectively. Situated below the upper face is a PC board (16A) which has the following functions:-

1. It contains electronics necessary to measure and display the pressure in the flow system downstream of laminar flow pathways, pressure difference (ΔP) across laminar flow pathways, and temperature and interpretive rock permeability (i.e. combining components (3A) and (4A) hereinbefore set forth.

2. It monitors output from both the pressure transducer for the flow system and the micromanometer recording the pressure different (ΔP) across selected laminar pathways in order to identify when steady state conditions have been attained.

3. It automatically records, processes and stores data for example, measurement of pressure downstream of laminar flow pathway, pressure differential (ΔP) across laminar flow pathway, temperature and interpretive rock permeability, once steady state conditions have been achieved.

4. Allows downloading of the data in ASCII format.

5. Processes and stores calibration data necessary to interpret rock permeability.

The probe assembly is formed into a device in which the pressure gauges (3 and 4) are readily visible and wherein a handle is provided with trigger means operating the on/off valve adjacent the probe tip (12).

When in use the probe gun assembly (17) is connected by means of tubing and tubing connectors to the portable gas source (15). The portable gas source (15) is operated by means of a

manual pump to charge the same with compressed air until the pressure value in the pressure gauge (1) reaches a pre-determined safe working pressure e.g. 5 bar. The pressure regulator (2) is then set for the intended permeability. In order to achieve a satisfactory value for differential pressure, it is usually necessary to open at least one of valves 9, 10 and 11 on a serial basis. This allows larger volumes of air to flow through the tube (18) without creating turbulence. Whether the valves 9, 10 or 11 and consequently coils 6, 7 and 8 are brought into operation will depend upon the substrate under test. However with experience the operator can soon tell which of these will be necessary. The sealing annulus seal (21) is then pressed into contact with the test specimen, for example a rock face, and a trigger (12A) actuated to operate the valve adjacent the tip (12) allowing a through-flow of air into the rock face. With a steady state established the differential pressure value from the differential pressure valve (3) is recorded along with the values from the pressure transducer and pressure indicator gauge (4). These values are later analyzed by comparison with a standard curve to produce a permeability value.

The basis of the mode of operation is as follows:-

Measurements are made by pressing the seal assembly (21) against a sample surface. During analysis of permeable media, the device of the invention measures the pressure drop across an operator-selected laminar flow pathway, and injection pressure at some location downstream of the flow pathways. The pressure drop (ΔP) along laminar flow pathways can be calculated for standard flow conditions and operating conditions using the Poiseuille equation (Equation 1) which describes fluid flow within a cylindrical capillary tube...

$$Q = \frac{\pi \cdot r^4 \cdot \Delta P}{8 \cdot \mu . L}$$

EQUATION 1

Where....

Q	=	Flow Rate (m^3/sec)
r	=	radius of capillary tube (m)
ΔP	=	pressure difference causing flow (Pa)
μ	=	viscosity of flowing fluid (Pa.sec)
L	=	Length of capillary tube (m).

Re-arranging Equation 1 to calculate ΔP for standard flow conditions cited (i.e. 5 psi injection pressure at 20°C) using for example the 2000cc/minute laminar flow pathway (length 35.7cm, radius 1.494mm) with nitrogen as the flowing gas (Equation 2) we obtain...

$$\Delta P = \frac{((2000/60)*10^{-6})*8*(1.74*10^{-5})*0.357}{\pi * (1.494*10^{-3})^4} = 104.6\text{Pa } (10.5\text{mm } H_2O)$$

EQUATION 2

Where the viscosity of Nitrogen (in $Pa.s^{-1}$) is determined by...

$$\pi = ((0.00005 * \text{Temp } ^\circ C) + 0.0164)*10^{-3}$$

EQUATION 3

The relative viscosity of N_2 with respect to air is 0.963. (therefor multiply μ by 1/0.963 to convert to air viscosity).

From the above, the flow rates of 2000cc/minute, the pressure drop (ΔP) through the 2000cc/minute laminar flow pathway is calculated as 10.46mm H_2O, under standard operating conditions (i.e. injection pressure of 5 psi). Data for other laminar flow pathways are summarised in Table 1.

The measured pressure data obtained by the probe permeameter can be used to calculate a normalised gas flow rate (F_{norm}) through the sample (Equation 4)....

$$F_{norm} = \Delta P \frac{LFE}{P_{cal}} * \frac{5}{P_{inj}}$$

EQUATION 4

Where ....

Fnorm	=	normalised flow rate (cc/min) with respect to standard injection pressure (5 psi)
ΔP	=	pressure drop in mm H_2O along selected Laminar Flow Pathway
LFE	=	maximum flow rate of selected Laminar Flow Pathway
P_{inj}	=	measured injection pressure (psi)
P_{cal}	=	calibrated pressure drop corresponding to the maximum flow rate of Laminar Flow Pathway selected (mm H_2O)

By selecting a suitable pathway, and measuring the pressure drop (ΔP) across the flow element when flowing gas through a collection of homogeneous rock samples of known permeability (determined by conventional Hassler Sleeve analysis), it is possible to create a calibration line for (ΔP) or calculated normalised flow rate versus permeability.

TABLE 1

	Capillary Radium m	Capillary Length m	Flow Rate m3/min	Temp °C	Absolute Viscosity Pa.sec	dP Pascals	dP mm H_2O
NITROGEN GAS FLOW							
2 cc LFE	0.000254	0.265	3.33333E.08	20	0.0000174	94.02	9.40
20 cc LFE	0.000381	0.149	3.33333E.07	20	0.0000174	104.42	10.44
200 cc LFE	0.0010795	0.962	3.33333E-06	20	0.0000174	104.62	10.46
2000 cc LFE	0.0014985	0.357	3.33333E-05	20	0.0000174	104.56	10.46
AIR FLOW							
2 cc LFE	0.000254	0.265	3.33333E-08	20	1.67562E-05	90.54	9.05
20 cc LFE	0.000381	0.149	3.33333E-07	20	1.67562E-05	100.56	10.06
200 cc LFE	0.0010795	0.962	3.33333E-06	20	1.67562E-05	100.74	10.07
2000 cc LFE	0.0014985	0.357	3.33333E-05	20	1.67562E-05	100.69	10.07

CLAIMS

1. A probe permeameter (1) comprising a source of compressed gas (15.20), a pressure regulator (2), at least one open coil of fine tubing (5) and at least one valve controlled coil of fine tubing (6.7.8) disposed in series, pressure indicating means (3A.4A) respectively upstream and downstream of said coils, and a gas nozzle (19) operatively associated with a sealing annulus (21), whereby with the nozzle urged into contact with a test specimen gas is delivered at laminar flow and wherein the pressure indicating means indicates the differential pressure generated in the specimen and hence the permeability thereof.

2. A probe permeameter according to Claim 1 wherein the source of compressed gas is a manually pressurisable container (15).

3. A probe permeameter according to either of the preceding claims provided with a plurality of valve controlled (9A. 10A.11A) fine tube coils to induce laminar flow at progressively higher gas through-puts.

4. A probe permeameter according to any preceding claim wherein the pressure indicating means upstream (3A) is a differential pressure gauge (3) and the pressure indicating means downstream (4A) is a pressure transducer and/or a pressure indicating means (4).

5. A probe permeameter according to any preceding claim wherein the compressed gas source is provided with a pressure gauge.

6. A probe permeameter according to Claim 1, and Claims 3 to 5 when dependent on Claim 1, wherein the compressed

gas source is a pressurised gas canister.

7. A probe permeameter according to any preceding claim wherein the pressure gauges (3 4) are electrically driven and provided with an output for computerised data.

8. A probe permeameter according to any preceding claim wherein the nozzle is remote from the device (1) and is connected via a conduit (18) to probe tip (12) and is provided at its operative end with a resilient sealing annulus (21) to seal against the sample under test and with means to blank off gas flow to provide a zero flow condition.

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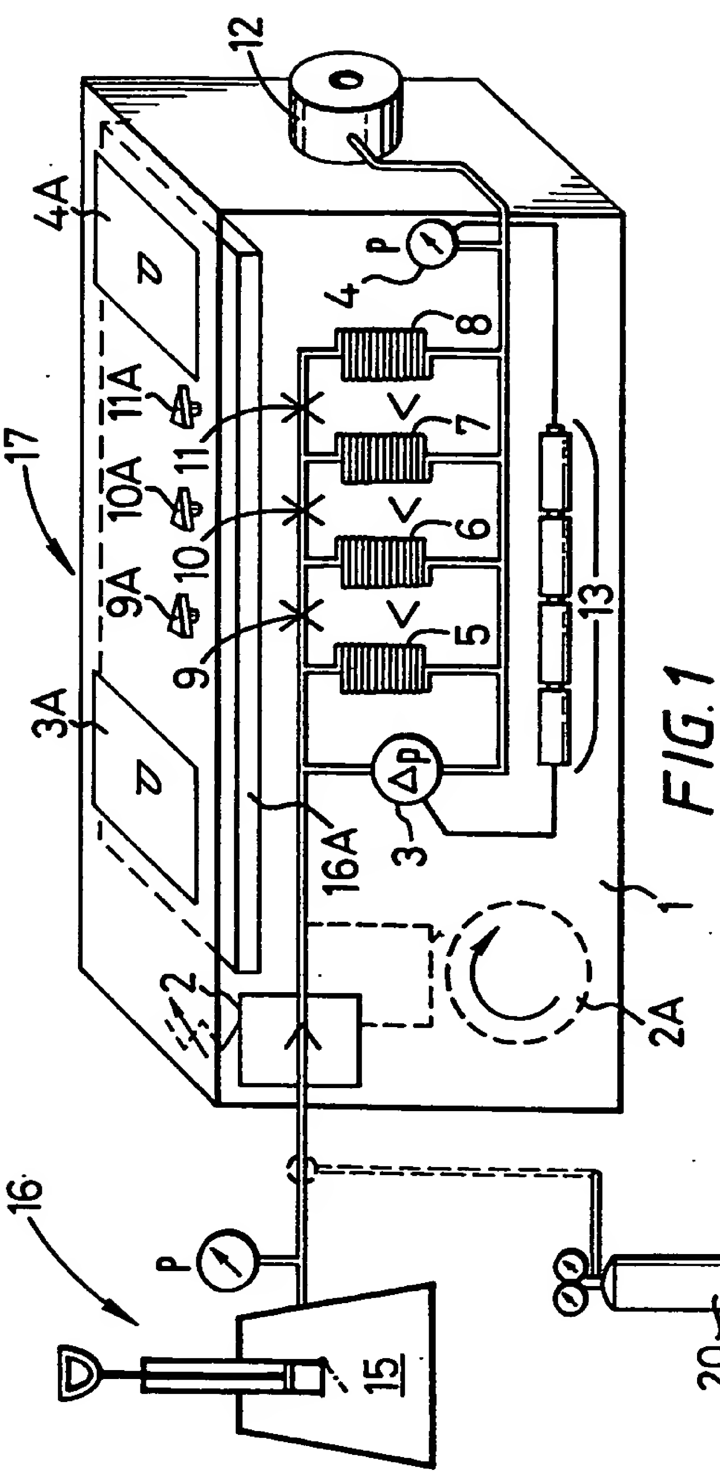

FIG.1

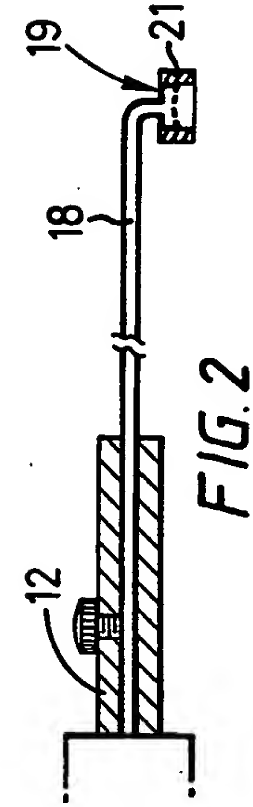

FIG.2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 94/01137

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 G01N15/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 146 514 (TRATEKNIKCENTRUM) 26 June 1985 see claims 3-8	1,5
A	GB,A,2 094 986 (BRITISH-AMERICAN TOBACCO) 22 September 1982 see claims 1-12	1
A	GB,A,2 161 942 (ROBERTSON RESEARCH INTERNATIONAL LIMITED) 22 January 1986 see claims 1-10	1
A	DE,B,10 63 832 (ZELLSTOFFFABRIK) 20 August 1959 see claims 1,2	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

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1

Date of the actual completion of the international search	Date of mailing of the international search report
24 August 1994	02.09.94
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Authorized officer Van den Bulcke, E

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/GB 94/01137

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-0146514	26-06-85	SE-B- 460800	20-11-89
		DE-A- 3475731	26-01-89
		SE-A- 8307045	21-06-85
GB-A-2094986	22-09-82	AU-B- 551029	17-04-86
		AU-A- 8124882	23-09-82
		CA-A- 1173667	04-09-84
		DE-A- 3209735	04-11-82
		US-A- 4462248	31-07-84
GB-A-2161942	22-01-86	NONE	
DE-B-1063832		NONE	

DEC 1980

TENT= ★ S03 K3410 D/40 ★SU -787-958

Abrasive tools relative permeability pneumatic tester - has ejection chamber communicating with bellows as pressure sensor to obtain reading by pressure rise

TENTH BEARING WKS · 03.07.78-SU-637695

(15.12.80) G01n-15/08

03.07.78 as 637695 (840MC)

Instrument for determn. of gas-permeability of porous products and contg. a measuring head (1) with a cylindrical nozzle has greater operating speed for use in non-destructive quality control of abrasive tools, e.g. grinding wheels, and it is useful in large-scale testing in mfg. and engineering plants, esp. bearing factories. By introducing ejection chambers (2) of slide type in communication with bellows (3) as press. sensor in place of a rotametric device, the measurements can be performed in 0.5-0.8 sec. instead of 2-3 sec.

Compressed air is admitted through the filter (18), distributor (17) and stabiliser (7) into channel (6) of the measuring head. The test object is placed on an elastic annular seal (10) of the ejection chamber. On applying press., the air is vented to atmosphere through nozzles (8,9) and pores of the test object. If test object permeability is such that a press. rise is produced, one bellows is distended and another compressed in obtaining a relative permeability reading by the scale (4). Bul.46/15.12.80. (4pp Dwg.No.1)

S3-F6